3.0 ECONOMIC BENEFIT OF IMPROVED LANDING CAPABILITY

3.1 Introduction

Section 2 provided an identification of the meteorological conditions which contribute to poor visibility. This section considers an analysis of the subsequent effect of poor visibility on airline operations. Operationally, poor visibility leads to delays, diversions and attendant cost penalties. The inclusion of equipment to provide added landing capability (ability to operate a lower minimums) presents a potential way to avoid some of these penalties. The intent of this section is to evaluate the cost benefit of improved landing capability and to provide the basis by which the cost of the additional equipment may be weighed against the cost benefit of this added capability in the sense of economic justification. The emphasis is placed upon the evaluation of the saving associated with improvement in terms of visibility increments. The magnitude of the saving is related to airline operating procedures and to the unique visibility characteristics of individual airports.

The effect of hazard warning and avoidance upon flight safety is neither small nor unimportant but it does have subjective facets which make a meaningful quantitative dollar evaluation difficult. Therefore, no effort is made either to quantify safety in terms of dollars or to include a safety value in the following analysis.

3.2 Poor Visibility and Operational Delays

Poor visibility has an adverse effect upon flight operations. It creates delays in landing and diversion to alternate airports because of inability to land. This section will present the recorded visibility statistics for a number of U.S. airports and use them to estimate the average delaytime and diversion probability for an aircraft attempting to land at a specific airport. The aircraft is characterized as having the capability to loiter near its destination for a specified maximum time before having to divert. Loiter capabilities of 30, 60, and 120 minutes are considered in the analysis.

The visibility statistics for the analysis were taken from the Climatological Summaries (Ref. 13). Data in a series of tables for each of 31 airports were used. These tables listed the total number of occurrences of visibilities at or below certain levels for a period of ten years. The number of occurrences were given in columns according to the duration of the occurrence. A part of these tables, for Stapleton International Airport at Denver, Colorado, is shown below.

TOTAL TIME AT OR BELOW EACH VISIBILITY CLASSED AS ONE INCIDENT
TABLE VI. (IRRESPECTIVE OF CEILING).

VISIBILITY (mi)	DURATION IN MINUTES										
	1-15	16-30	31-45	46-60	61-90	91-120	121-180	181-240	241-360	361-480	481+
3/8	43	34	23	27	27	15	21	11	4	1	
5/16	32	22	25	19	26	15	16	9	4	1	
1/4	32	21	25	20	25	15	16	9	4	1	
3/16	14	13	10	12	9	5	11	3	3		
1/8	11	11	10	10	10	5	10	4	2		
1/16	2	6	6	5	1	3	6	3			
0	4	1			1	2	3	2			

The occurrences are cumulative. The total duration of visibility at or below a specific level is considered as one occurrence. For example, if the visibility were 1/4 mile for 25 minutes and 3/16 mile for five minutes during the period of interest, it would be classified as four occurrences. There would be three entries under 16-30 minutes duration, at 3/8, 5/16 and 1/4 mile, and a fourth entry under 1-15 minutes at 3/16 mile. The values for the 1/2 mile visibility entries were developed by extrapolation from the data in Climatological Summaries.

The objective of the analysis was to yield typical delay times and diversion probabilities using actual visibility conditions and typical loiter capabilities for large, medium and small transport aircraft. The equations used in the analysis are derived in the first part of Appendix A. .Generally speaking, they describe three situations which contribute to aircraft delay and diversion. First, if the aircraft loiter capability is greater than the duration of poor visibility, the aircraft simply waits for the weather to clear and lands. Second, if the aircraft loiter capability is less than the duration of poor visibility, then there is a finite probability that the aircraft, after waiting as long as it can, will have to divert. Third, under the same conditions, there is a finite probability that the aircraft can successfully wait until the weather clears. The last two alternatives depend upon when, during the period of poor visibility, the aircraft encounters it. At each airport, three separate loiter capability times of 30, 60 and 120 minutes are used. The mean delay times per landing and the probability of diversion calculated for visibilities at or below the seven listed values: 1/2, 3/8, 1/4, 3/16, 1/8, 1/16, and 0 miles. All calculations were carried out on a digital computer.

Note that the delay times and diversion probabilities presented in this form correspond only to the times spent in weather below the landing minimum. They do not include the additional delays which are created by traffic accumulation during periods of poor visibility. These additional delays created by the queuing effect are taken into account in the latter part of Appendix A and in the analysis of the following subsection.

The mathematical background and the tabular results of this work are shown in Appendix A. Equations 1 through 4 of that Appendix,are the basis for the results shown in the Tables. The tables present the basic visibility data which was taken from the Climatological Summaries. The tables also present the mean delay time per landing and the probability of diversion for each of the assumed loiter capabilities and for visibility conditions at or below each of the seven listed values. The results of this work will not be

discussed here because the inclusion of operating rules, delay and diversion costs, and the compounding delay due to the traffic congestion lead to a much more meaningful result. These factors are added to the analysis in the next subsections.

3.3 Cost of Delays, Diversions and Cancellations

The effect of poor visibility in creating delays and diversions was introduced above. In this section, the typical dollar cost of delay, diversions and cancellations are briefly stated. These cost figures are later used in the evaluation of cost penalties associated with assumed route structures and specific airports.

The cost figures presented below are typical of three different types of aircraft which are used on different route structures:

Aircraft #1:	A large four-engine jet,
Routes:	transcontinental, intercontinental,
Flight Plan:	may delay for two hours; diverts after a 2-hour delay
Aircraft #2:	A medium two or three-engine jet,
Routes:	regional,
Flight Plan:	May delay for one hour; diverts after a one-hour delay; cancels flight if a delay longer than two hours is anticipated
Aircraft #3:	Heavy twin turbo-prop,
Routes:	commuter
Flight Plan:	May delay up to 1/2 hour; delay takeoff for anticipated delay up to one hour; cancel flight if a delay of longer than one hour is expected.

The cost figures below are taken from Reference 14. The costs of diversions and cancellations were estimated from average figures given in the reference. The cancellation figure for Aircraft #3 was not available explicitly, but it was estimated from figures that pertained to Aircraft #2. In addition, all of the cost figures were adjusted upward to account for a five year passage of time.

The Figures in Table II-12, following, representing the cost of delays, range from $ 250/hr for the small aircraft (#3) to $ 870/hr for the large aircraft (#1).

TABLE II-12. COSTS OF DELAY, DIVERSION, AND CANCELLATION.

Aircraft Number:	1	2	3
Delay	$14.50/min.	$10.20/min.	$4.10/min.
Diversion	$1700	$1460	———
Delayed Takeoff	———	———	$0.41/min.
Cancellation	———	$1300	$1150

3.4 Method of Computation

The cost benefits of improved landing capability are obtained by combining the visibility data with the delay and diversion cost figures. The visibility data and the evaluation of it, which is contained above, assumes that the landing may be accomplished as soon as the weather clears. In reality, the delay may be further propagated because of accumulated traffic. An analysis of delays and diversions and the inclusion of traffic buildup is contained in the Appendix A. The accumulated traffic affects the original delay figures in two ways. First, it lengthens the delay time for aircraft which arrived in bad weather. This effect can also produce additional diversions. Second, it creates delays for those aircraft which arrive shortly after the weather clears. In the analysis of Section 3.2, this delay was not considered.

The objective here is to find the cost penalties related to the inability to land in individual intervals of visibility. The intervals used are assumed to be consistent with the visibility intervals in which the visibility data is presented in Appendix A.

The average delays and the diversion probabilities are computed for maximum aircraft loiter capabilities of 30, 60 and 120 minutes. These delays and diversion values are computed from the visibility data and the traffic arrival and landing rates for a particular airport. The landing rate for a finite number of specific airports is determined by the FAA specifying a maximum hourly rate of operations during IFR conditions. For other airports, an estimate of the rate of operations can be made from the IFR runway configuration and landing rates stated in Reference 14. The value of the landing rate, r_o, for an airport is determined by assuming that if several aircraft have been waiting to land, 80% of the operations will be landings until the overload is cleared.

The aircraft arrival rate, r_i, for a given terminal area is determined from the annual number of operations at that airport. The hourly arrival rate is assumed to be half the total number of operations divided by 365x16 since traffic pattern studies have shown that nearly all operations occur during a 16 hour period of the day.

So, arrival rate, $r_i = \frac{NO}{11680}$

where NO = the number of annual operations. The values of arrival rate developed in this manner are sixteen hour averages, so the values of delays derived from them reflect only an average value, and not the peak value, which could be much higher. In some cases the arrival rate exceeds the landing rate during peak hours, resulting in a build-up of waiting aircraft rather than a decrease.

The table (II-13) below lists the annual operations, the peak IFR operations, and the values of landing rate and arrival rate for eight airports in the years 1967 and 1970. The annual operations for 1967 are from Reference 15 and the figures for 1970 are estimates.

TABLE II-13. TYPICAL AIRPORT OPERATIONS

Airport	Thousands of Operations		Peak IFR Operations (per hr)	Landing Rate (per hr)	Arrival Rate (per hr)	
	1967	1970			1967	1970
JFK	481.5	580.0	80R	64.0	41.2	49.6
Newark	260.0	308.0	60R	48.0	22.3	26.4
Baltimore	208.0	260.0	52	41.6	17.8	22.3
Miami	446.9	537.0	81	64.8	38.3	46.0
O'Hare	643.8	819.0	135R	108.0	55.1	70.2
Los Angeles	482.8	602.0	94	75.2	41.3	51.6
Atlanta	362.6	508.0	90	72.0	31.1	43.5
Cleveland	318.6	426.0	71	56.8	27.3	36.5

(R means explicitly stated values. The remaining values of IFR Ops are estimates.)

The costs of delays and diversions are calculated in the following manner. The reader is referred to Appendix A, for a more thorough discussion of the analysis. The important variables are:

W — The length of time where the visibility is below the minimum required for landing.

L — The loiter capability (maximum delay) of the aircraft.

The following four variables refer to a specific category of visibility:

P(D) — Probability of diversion where the duration of bad weather exceeds the loiter capability.

D_s — Average delay per landing where the loiter capability exceeds the bad weather duration.

D_e — Average delay per landing where the aircraft arrives near the end of a long period of bad weather and is able to wait long enough to land.

D_d — Average delay per attempted landing spent before diverting ($W > L$). (Note that D_d is not contained in D_e).

Additional subscripts, such as D_{s120}, indicates that D_s is to be evaluated at $L = 120$ minutes.

The following variables relate to costs:

CDL — Cost of a delay/minute.

CDV — Cost of a diversion.

CCL — Cost of a cancellation.

CHT — Cost of delaying takeoff/minute.

The numerical values for these cost elements were presented in Table II-12.

In this analysis and in the computations for this section, three typical route structures and operating guidelines are assumed.

Assumed Route Structure 1.

Stage lengths: 3600nm, transcontinental, intercontinental

Aircraft: large, four-engine jet

Landings/Year: 600

Flight Plan: Delay up to two hours, divert if delay lasts beyond two hours (L = 120 minutes)

Delay Cost per Flight = $(D_{s120} + D_{e120})$ CDL

Diversion Cost per Flight = $P(D)_{120}$ CDV + D_{d120} CDL

Assumed Route Structure 2.

Stage length: 600nm, regional carrier

Aircraft: medium, 2-3 engine jet

Landings/Year: 2400

Flight Plan: Delay up to one hour. Divert if delay lasts beyond one hour. Cancel flight if delay will last beyond two hours (L = 60).

Delay Cost per Flight = $(D_{s60} + D_{e60})$ CDL

Diversion Cost per Flight = $(P(D)_{60} - P(D)_{120})$ CDV + $(D_{d120} - D_{d60})$ CDL

Cancellation Cost per Flight = $P(D)_{120}$ CCL

Add to get the total cost per flight.

Multiply by 2400 flights to get the total cost per year.

Assumed Route Structure 3.

Stage Length — 200 nm, Commuter

Aircraft: — Heavy twin turbo-prop

Landings/Year: — 3000

Flight Plan: — Delay up to one/half hour. Delay takeoff one/half hour if delay will last up to one hour. Cancel flight if delay will last beyond one hour.

Delay Cost per Flight $= (D_{s30} + D_{e30})\ CDL$

Delayed Takeoff Cost per Flight $= (P(D)_{30} - P(D)_{60})\ 30CHT + ((D_{s60} + D_{e60}) - (D_{s30} + D_{e30}))\ CDL$

Cancellation Cost per flight $= P(D)_{60}\ CCL$

Add to get the total cost per flight.

Multiply by 3000 flights to get the total cost per year.

Once the computations have been made for each visibility category, they are summed to get the total costs due to visibilities below one/half mile.

3.5 Results of Low Visibility Cost Computations

The results of cost computations for eight airports and three route structures and the six visibility categories appear in Appendix A. They are organized so that all of the results for a given airport for one year appear on one page. There are five tables of data on a page. The first is a listing of the source visibility data taken from the tabular data of the Climatological Summaries (Ref. 13), with the addition of the estimated 1/2 mile data mentioned earlier. It should be noted that the methods used to determine 1/2 mile data were very conservative, and so the resulting dollar figures associated with Category I are also conservative estimates. Following this are the values associated with delay propagation, unique to that airport and year. The second table lists mean delays per landing

and probabilities of diversion corresponding to total allowable delays of 30, 60 and 120 minutes, computed in accordance with equations 9 through 12 in Appendix A. The mean delay per landing stated is the total mean delay ($D_s + D_e + D_d$). The contributions to delay and diversion probability of each individual category are not shown. The three remaining tables correspond to the three route structures defined above. For each route structure and for each visibility category, the contributions to total cost of delays, diversions, cancellations and delayed takeoff (where applicable) are shown. These figures are calculated on a per flight basis. The per flight totals are multiplied by the number of flights per year to get the total costs per year.

3.6 Conclusions: Benefits of Specific Improvements in Capability

It is apparent from these cost computations that the yearly losses due to poor visibility vary widely depending on the airport and route structure. The variation between airports is certainly to be expected because of the different visibility statistics and different ways in which traffic congestion propagates delays. The variations between route structures is relatively consistent from airport to airport, however. Route structure One always has the lowest total yearly cost and route structure Two has the highest. This is caused primarily by the variations in basic operating costs and the number of landings per year. Route structure One has the highest operating costs but there are relatively few landings made per year. Route structure Two has somewhat lower costs but four times as many landings. Route structure Three has significantly lower operating costs, but due to the high cost of cancellations and the large number of landings per year, this route has total losses that are nearly as high as those of route structure Two.

The best way to determine the benefits of a particular improvement in landing capability is to pick a route structure and an airport (or an average for a combination of airports), that represent a particular air carrier's situation. Then add together the total losses corresponding to the visibility ranges in which landings could be made with the improved system. This figure can be compared to the yearly cost of purchasing and maintaining such a system. For example, let us assume route structure Two with landings in Baltimore as projected for the year 1970 and equipment that would allow landings in visibilities down to one-quarter mile. The yearly benefit of such a system would be $2365 + $5187 = $7552. If we assume five year depreciation plus five percent of purchase cost per year for maintaining etc., this would pay for $30,000 worth of equipment. (Note that this is a simple computation and does not reflect interest charges, present value of the money or other considerations). Again, examining the Baltimore table, we see that capability down to 3/16 mile could increase the benefit by another $10,423 to a total of $17,975. This yearly amount would pay for $72,000 worth of equipment.

One of the most interesting results of the data on these tables is the distinct lack of correlation between the benefits derivable from a small increase in capability and the benefits of a system with capability down to zero visibility. Compare, for example, route structure Two at Baltimore and Newark. The total of the costs per year at Baltimore is nearly twice the total at Newark. But the total of the benefits down to 1/4 mile are of the same order of magnitude. The totals for Los Angeles and New York JFK are roughly equal, but the benefits of a system good to 3/16 mile at JFK is twice as great at Los Angeles. These results are caused by a wide variation in the way the visibility occurrence data is distributed. It can also be affected by the methods used for observing and reporting visibility data. Note that at JFK the number occurrences of higher visibility is very high, and the occurrences of low visibility is very low. At Los Angeles the changes in occurrences with changes in visibility are not nearly so great.

The most significant result of these computations is the demonstrated fact that the cost benefit of having improved capability increases when the length of the route, and therefore the size and cost of the aircraft decreases. This fact directly contradicts the usual practice of spending a fixed per cent of the cost of the aircraft on avionic systems. Quite obviously, this effect is directly caused by the assumptions made in generating the cost model. For example, a large cost of diversion would tend to stress the importance of individual landings. This subsequently relates the greatest cost benefit to the aircraft making the greatest number of landings regardless of the type of aircraft.

Using the figures for Baltimore, let us calculate the ratio of cost of low visibility to total revenue per flight.

TABLE II-14. RELATIONSHIP OF LOW-VISIBILITY COST TO TOTAL REVENUE ON A PER-FLIGHT BASIS.

	Assumed Route Structure		
	1	2	3
Average # Passengers	100	60	35
One-Way Fare	$225	$50	$30
Total Revenue	$ 22.5K	$ 3K	$ 1.05K
Low Visibility Cost	$ 35.04	$19.25	$12.82
% of Total Revenue	0.16%	0.64%	1.22%

In this case, the percent of total revenue per flight lost due to the inability to land in visibilities less than 1/2 mile is nearly ten times as great for the twin turboprop aircraft as it is for the large four-engine jet. Indeed, the loss to smaller aircraft is a very significant portion of the profit margin of the aircraft. An increase of landing capability to 3/16 mile for a turboprop landing at Baltimore would reduce costs by 0.5% of gross revenues. If the cost of the equipment required to give this capability were less than $60,000, the result would be a net increase in profits.

In general, the supporting data in this analysis leads to the qualified conclusion that the IALM function is most cost effective to the regional carriers - or stated another way, the carrier whose combination of operating cost per hour and number of landings per year results in the largest cost benefit appears to be the hypothetical route structure Two operation. Certainly, a modification of the arbitrarily chosen ground rules for the analysis will change the numerical results somewhat, but the logic of the system benefits will tend to keep the ultimate conclusions similar to those shown in this section.

The preceding discussion does not take into account the obvious benefits of lives and aircraft saved due to the reduction in ground collision accidents, nor the economic benefit from any reduction in insurance rates.

3.7 Summary

In this section visibility statistics, costs of individual delays and diversions, aircraft loiter capability, and airline operating practices have been combined to develop the cost penalties associated with various intervals of visibility. It is noted here that the treatment in this particular analysis was limited to visibilities of one/half mile and less. There is an additional benefit which is available in providing for the full exploitation of capability down to one/half mile visibility. The fact that landing minimums at some airports are limited to visibilities above one/half mile is established in Section 4.

To summarize the dollar cost savings which are available, the data from the tables of Appendix A is retabulated here. The dollar savings available from a full exploitation of Category II are presented for several airports and the assumed route structures which were used in the analysis above. The summary table is shown below.

TABLE II-15. ANNUAL COSTS ASSOCIATED WITH THE VISIBILITY INTERVAL 3/16 MILE TO 1/2 MILE.

Airport	Assumed Route Structure		
	1	2	3
Atlanta	$ 8,004	$ 16,951	$ 14,736
Baltimore	8,176	17,975	14,981
Chicago (O'Hare)	4,719	10,042	8,333
Cleveland	4,273	8,972	7,587
Los Angeles	6,417	13,218	11,303
Miami	1,551	3,528	2,610
Newark	5,553	12,004	10,485
New York (JFK)	13,022	26,688	21,241

The figure must be weighted with aircraft usage of individual airports to arrive at a true picture of the cost per aircraft. For example, if a medium range aircraft (route structure Two) were assigned to fly back and forth between New York (JFK) and Chicago (O'Hare) with half the total landings being made at each of these airports, the dollar saving of reducing the visibility limit from 1/2 mile down to 3/16 mile is the average of the two values in the table; that is, $18,365. If an intermediate stop were included in Cleveland, the saving would change to a new value. Assuming the same number of landings per year as before, which may be conservative, the potential savings become $13,668 annually. This saving should be sufficient to justify equipment costs on the order of $50,000.